NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL NOTE 3244

AERODYNAMIC CHARACTERISTICS OF THE

NACA 64-010 AND 0010-1.10 40/1.051 AIRFOIL SECTIONS

AT MACH NUMBERS FROM 0.30 TO 0.85 AND REYNOLDS

NUMBERS FROM 4.0×10^6 TO 8.0×10^6

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NACA

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SUMMARY

A short two-dimensional investigation has been made in the Langley low-turbulence pressure tunnel to determine the aerodynamic character-istics of the NACA 64-010 and 0010-1.10 40/1.051 airfoil sections. The investigation covered a Mach number range from 0.30 to 0.85 and the corre-sponding Reynolds number range extended from 4.0×10^6 to 8.0×10^6. The purpose of the investigation was to determine the extent to which the relative merits of the two airfoil sections, as indicated by previous investigations (NACA RM A9G18 and RM A9E31) at Reynolds numbers from 1.0×10^6 to 2.0×10^6, might be altered by increases in the Reynolds number. The results indicated that the increment between the higher drag of the NACA 0010-1.10 40/1.051 airfoil section and the drag of the NACA 64-010 airfoil section shown by the data of NACA RM A9G18 and RM A9E31 for moderate lift coefficients and relatively high subsonic speeds was much smaller in the present higher Reynolds number investigation.

INTRODUCTION

A recent airfoil-selection problem involved a choice between the NACA 64-010 section and a 10-percent-thick section of the modified NACA 4-digit-series family. A comparison of the data of reference 1 for the modified 4-digit-series section with those of reference 2 for the NACA 64-010 section indicated that the modified section had the highest drag-divergence Mach number for the low lift coefficient, high-speed condition; whereas the drag of the NACA 64-010 section was lower than that of the modified section for the cruise condition at moderate lift coefficients. The investigations of references 1 and 2 were made at relatively low Reynolds numbers (R = 1.0×10^6 to 2.0×10^6), how-ever, which raised a question as to the effect of increasing the Reynolds

number on the comparative drag characteristics of the two airfoil sec-
tions. Since the relative merits of the two families of airfoils have
been of considerable interest in the past few years, a short two-
dimensional investigation was undertaken in the Langley low-turbulence
pressure tunnel to determine the effect of Reynolds number on the drag
characteristics of the NACA 64-010 airfoil section and the 10-percent-
thick, modified NACA 4-digit-series airfoil section. Lift, drag, and
pitching-moment data are presented herein for the two airfoil sections.
The Mach number range of the investigation was from 0.30 to 0.85 and the
corresponding Reynolds number range was from 4.0×10^6 to 8.0×10^6.

SYMBOLS

x distance along chord

y distance normal to chord

α section angle of attack

c_l section lift coefficient

c_d section drag coefficient

$c_{m_{c/4}}$ section pitching-moment coefficient about quarter chord

R Reynolds number based on wing chord and free-stream velocity
             and density

M free-stream Mach number

APPARATUS AND TESTS

The two airfoils investigated were the NACA 0010-1.10 40/1.051 and
the 64-010 sections. The designation NACA 0010-1.10 40/1.051 describes
an airfoil which was obtained by modifying the NACA 0010 basic thickness
form. The 0010 appearing in the designation indicates a symmetrical
airfoil of 10-percent thickness; the 1.10 indicates the size of the
leading-edge radius in percent of the chord; the 40 indicates the
position of maximum thickness in percent of the chord; and the 1.051 is
an index number which is indicative of the trailing-edge angle with the

actual angle being twice the arc tangent of the product of the thickness-chord ratio and the index number 1.051. (It is perhaps of interest that the NACA 0010-1.10 40/1.051 section is similar to the well-known NACA 0010-64 section except for a reduced trailing-edge angle.) Both models were of 1-foot chord and were constructed of aluminum alloy. Ordinates of the two airfoil sections are given in table I and sketches of the two profiles are shown in figure 1.

The tests were made in the Langley low-turbulence pressure tunnel (ref. 3). The test section of the tunnel measures 3 feet by $7\frac{1}{2}$ feet and was so designed that the models, when mounted in the tunnel, completely spanned the 3-foot dimension. The model passed through slots in the tunnel walls and was attached to the strain-gage balance which was employed for lift, drag, and pitching-moment measurements. Labyrinth-type seals were provided at each end of the model to minimize the effect of air leakage through the slots in the tunnel wall. A more complete description of the technique of making two-dimensional measurements with the strain-gage balance may be found in reference 4.

The tests of each model consisted in measurements of the lift, drag, and pitching moment for angles of attack from -2° to 7° and for a Mach number range extending from about 0.30 to 0.85. An atmosphere of Freon-12 at a stagnation pressure of approximately 24 inches of mercury absolute was maintained in the tunnel for all the tests. The relationship between Reynolds number and Mach number for this stagnation pressure and a Freon purity of 95 percent by weight is shown in figure 2. The model surfaces were polished to a high degree of smoothness at the time of model installation in the tunnel. The drag coefficients measured, however, probably do not correspond to extensive regions of laminar flow, since the use of Freon-12 as a test medium makes unfeasible the almost continuous attention to model surface condition which is required in order to maintain extensive laminar layers.

CORRECTIONS AND PRECISION OF MEASUREMENT

Corrections for wind-tunnel-wall effects have been applied to all the data according to the methods of reference 5. Conversion of the data obtained in Freon-12 to equivalent air data has been carried out by the method of reference 6. The choking Mach numbers in air were determined from the measured values in Freon by the methods of reference 6 and varied from about 0.875 to 0.850 as the angle of attack varied from 0° to 7°.

The accuracy of the measured quantities has been estimated on the basis of the limitations of the balance and is indicated for various test conditions in the following table:

M	c_l	c_d	$c_{m_{c/4}}$
0.85	± 0.001	± 0.0003	± 0.0002
.60	± .002	± .0006	± .0003
.35	± .005	± .0015	± .0008

RESULTS AND DISCUSSION

The basic data obtained in the investigation are presented in figures 3 to 8 in the form of section lift, drag, and quarter-chord pitching-moment coefficient against Mach number for various angles of attack. Lift-drag polars obtained from cross plots of these data are presented in figure 9 for several Mach numbers. A study of the drag polars given in figure 9 indicates the same trends as shown by a comparison of the data of references 1 and 2. The drag coefficients of the NACA 0010-1.10 40/1.051 airfoil section appear in most instances to be somewhat higher than those of the NACA 64-010 airfoil section for Mach numbers up to 0.75 and lift coefficients above 0.10. For Mach numbers above 0.75, the advantage seems to be with the NACA 0010-1.10 40/1.051 airfoil section, at least for certain portions of the lift-coefficient range. A comparison of the section drag characteristics of the two airfoil sections as determined in the present investigation and in the investigations of references 1 and 2 is provided in figure 10 in which section drag coefficient is plotted against Mach number for section lift coefficients of 0.2, 0.4, and 0.6. The most significant differences between the results obtained in the investigations of references 1 and 2 and those of the present higher Reynolds number investigation are seen in the data for section lift coefficients of 0.4 and 0.6 at Mach numbers below the force break. For these conditions, the present data indicate the increment in drag between the two airfoils to be smaller in comparison with the increments shown by the data of references 1 and 2.

CONCLUDING REMARKS

A short two-dimensional investigation has been made in the Langley low-turbulence pressure tunnel to determine the aerodynamic characteristics of the NACA 64-010 and 0010-1.10 40/1.051 airfoil sections. The results indicated that the increment between the higher drag of the NACA 0010-1.10 40/1.051 airfoil section and the drag of the NACA 64-010 airfoil section shown by the data of NACA RM A9G18 and RM A9E31 for moderate

lift coefficients and relatively high subsonic speeds was much smaller in the present higher Reynolds number investigation.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., February 24, 1954.

REFERENCES

1. Summers, James L., and Graham, Donald J.: Effects of Systematic Changes of Trailing-Edge Angle and Leading-Edge Radius on the Variation With Mach Number of the Aerodynamic Characteristics of a 10-Percent-Chord-Thick NACA Airfoil Section. NACA RM A9G18, 1949.

2. Hemenover, Albert D.: Tests of the NACA 64-010 and 64A010 Airfoil Sections at High Subsonic Mach Numbers. NACA RM A9E31, 1949.

3. Von Doenhoff, Albert E., and Abbott, Frank T., Jr.: The Langley Two-Dimensional Low-Turbulence Pressure Tunnel. NACA TN 1283, 1947.

4. Loftin, Laurence K., Jr., and Von Doenhoff, Albert E.: Exploratory Investigation at High and Low Subsonic Mach Numbers of Two Experimental 6-Percent-Thick Airfoil Sections Designed To Have High Maximum Lift Coefficients. NACA RM L51F06, 1951.

5. Allen, H. Julian, and Vincenti, Walter G.: Wall Interference in a Two-Dimensional-Flow Wind Tunnel, With Consideration of the Effect of Compressibility. NACA Rep. 782, 1944. (Supersedes NACA WR A-63.)

6. Von Doenhoff, Albert E., Braslow, Albert L., and Schwartzberg, Milton A.: Studies of the Use of Freon-12 As a Wind-Tunnel Testing Medium. NACA TN 3000, 1953.

TABLE I

ORDINATES FOR NACA 64-010 AND 0010-1.10 40/1.051 AIRFOIL SECTIONS

NACA 64-010	
x, percent chord	y, percent chord
0	0
.5	.820
.75	.989
1.25	1.250
2.5	1.701
5	2.343
7.5	2.826
10	3.221
15	3.842
20	4.302
25	4.639
30	4.864
35	4.980
40	4.988
45	4.843
50	4.586
55	4.238
60	3.820
65	3.345
70	2.827
75	2.281
80	1.722
85	1.176
90	.671
95	.248
100	0

L.E. radius: 0.720 percent chord

NACA 0010-1.10 40/1.051	
x, percent chord	y, percent chord
0	0
1.25	1.466
2.5	1.966
5.0	2.589
7.5	3.009
10	3.337
15	3.845
20	4.240
30	4.791
40	5.000
50	4.783
60	4.197
70	3.338
80	2.305
90	1.193
95	.638
100	.100

L.E. radius: 1.10 percent chord

NACA 64-010

NACA 0010-1.10 40/1.051

Figure 1.- Profile shapes of NACA 64-010 and 0010-1.10 40/1.051 airfoil sections.
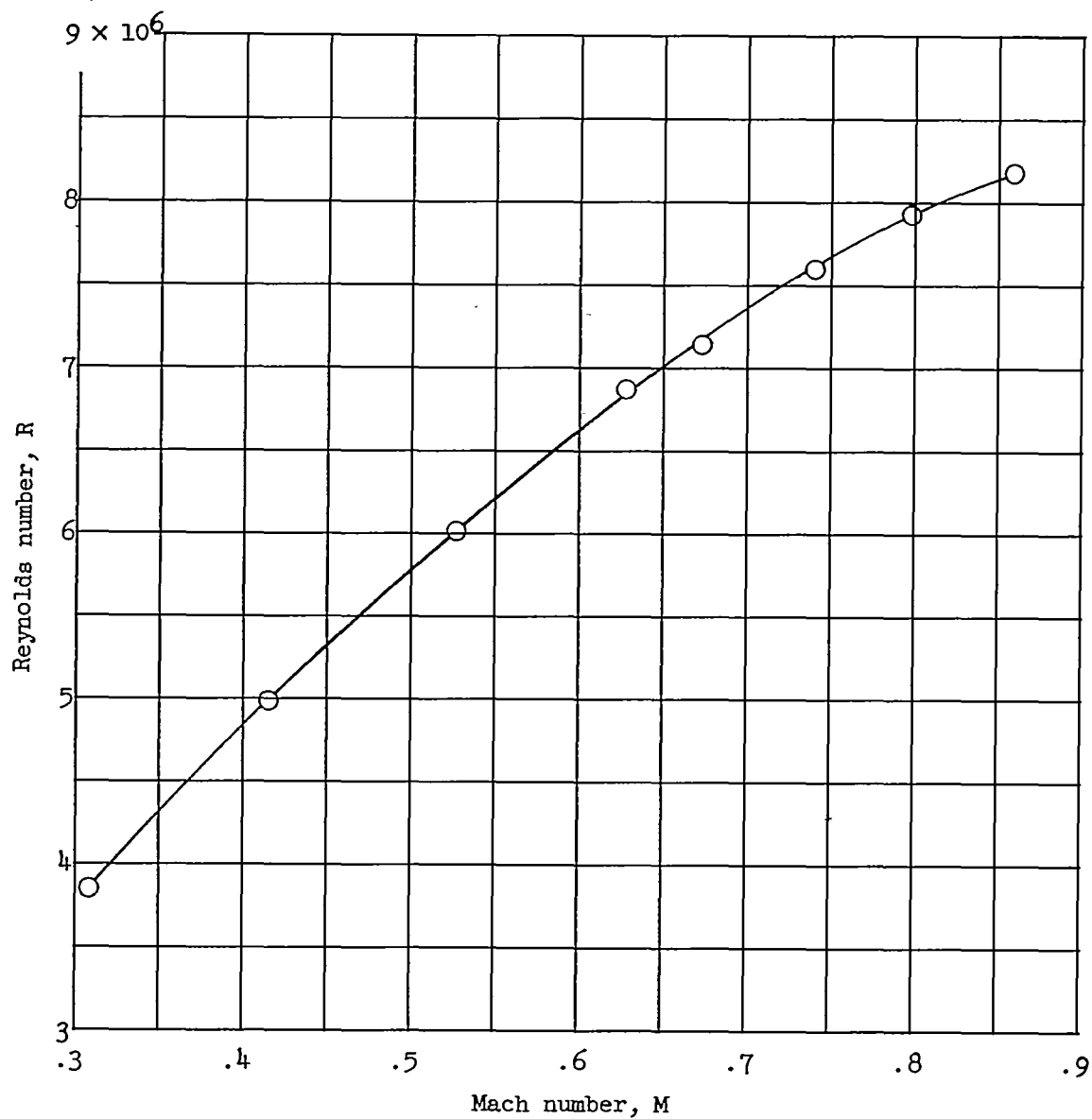
Figure 2.- Approximate variation of Reynolds number with Mach number for stagnation pressure of 24 inches of mercury absolute and Freon purity of 95 percent by weight.
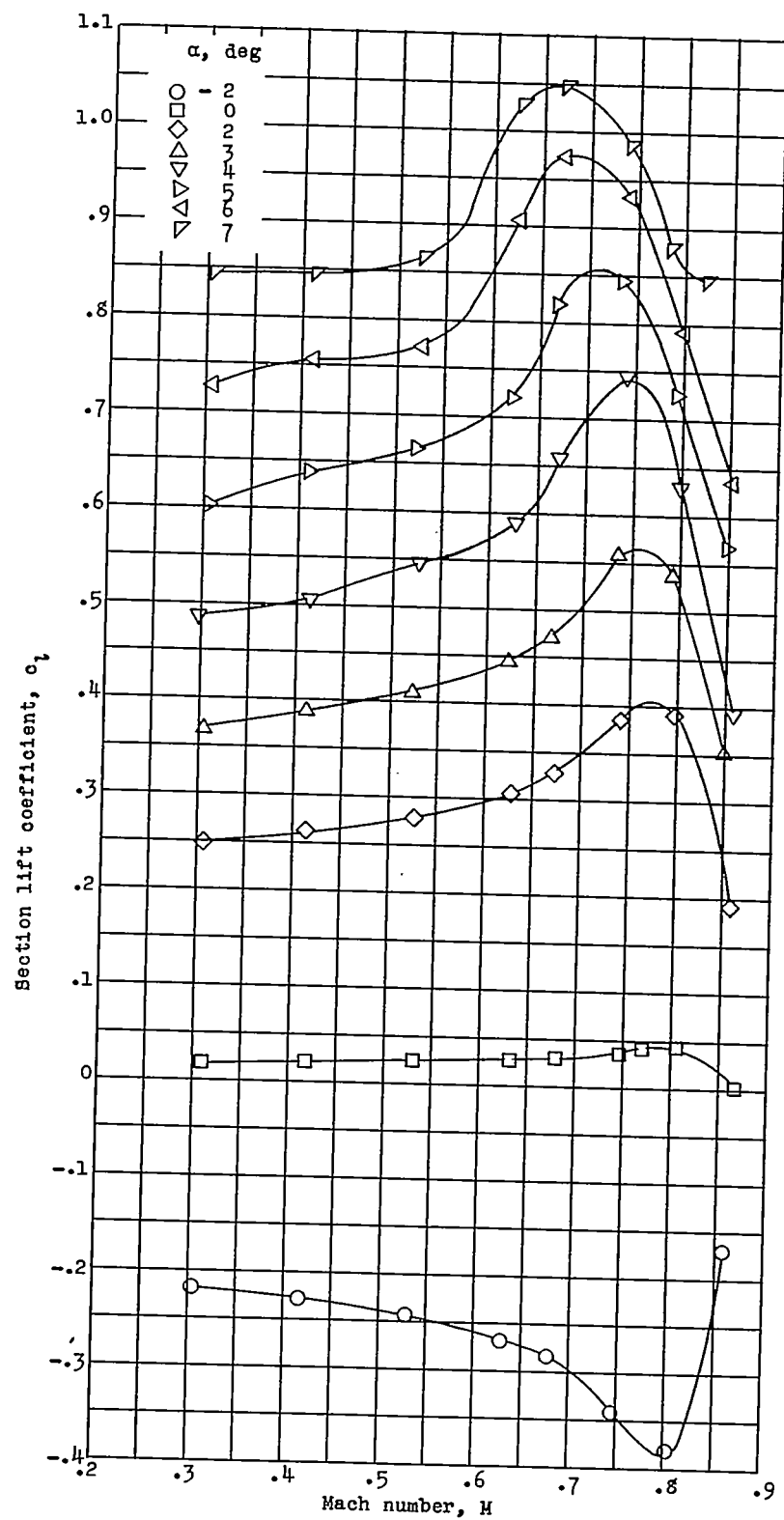
Figure 3.- Section lift coefficient of NACA 64-010 airfoil section as a function of Mach number for various angles of attack.
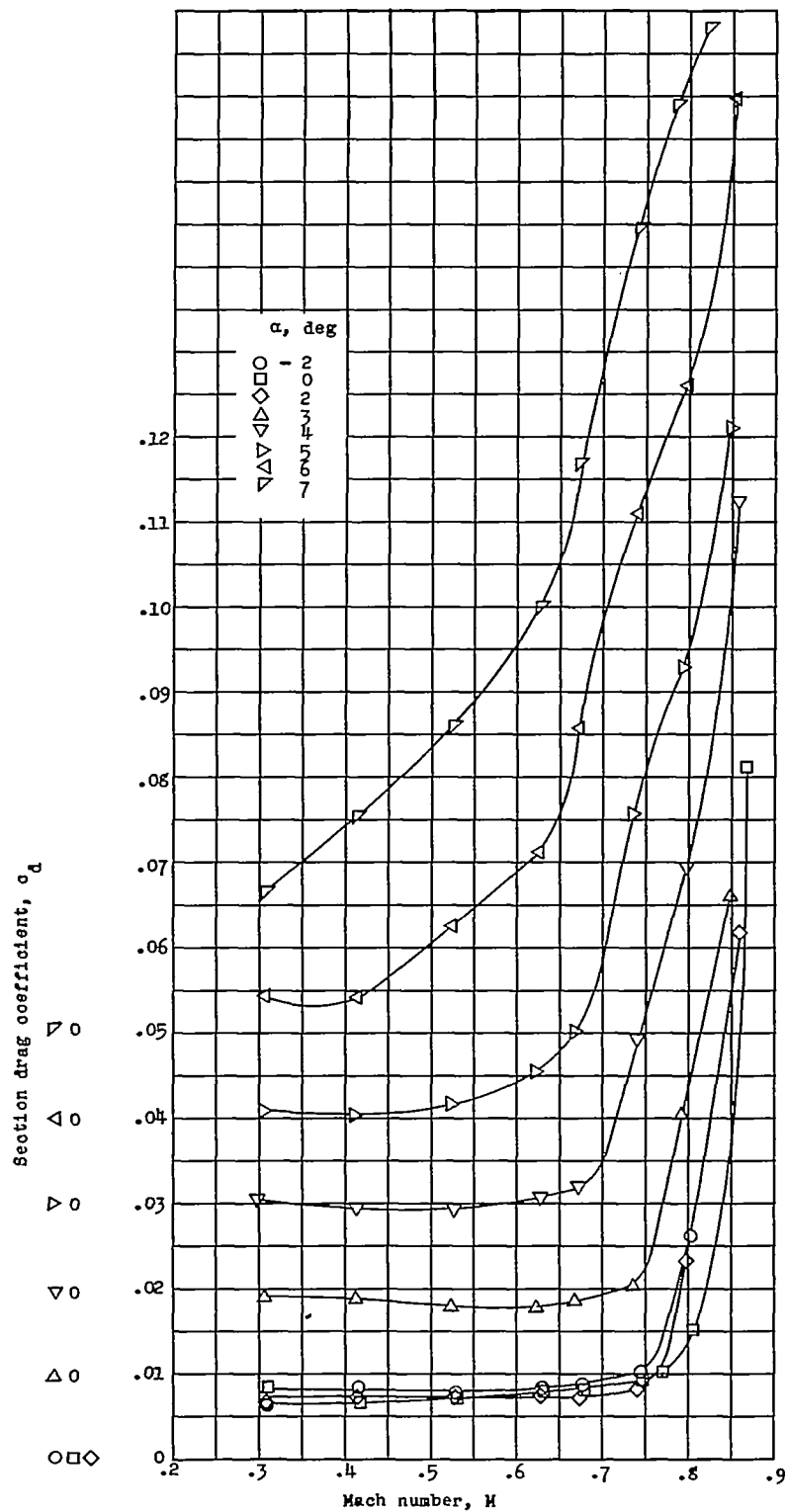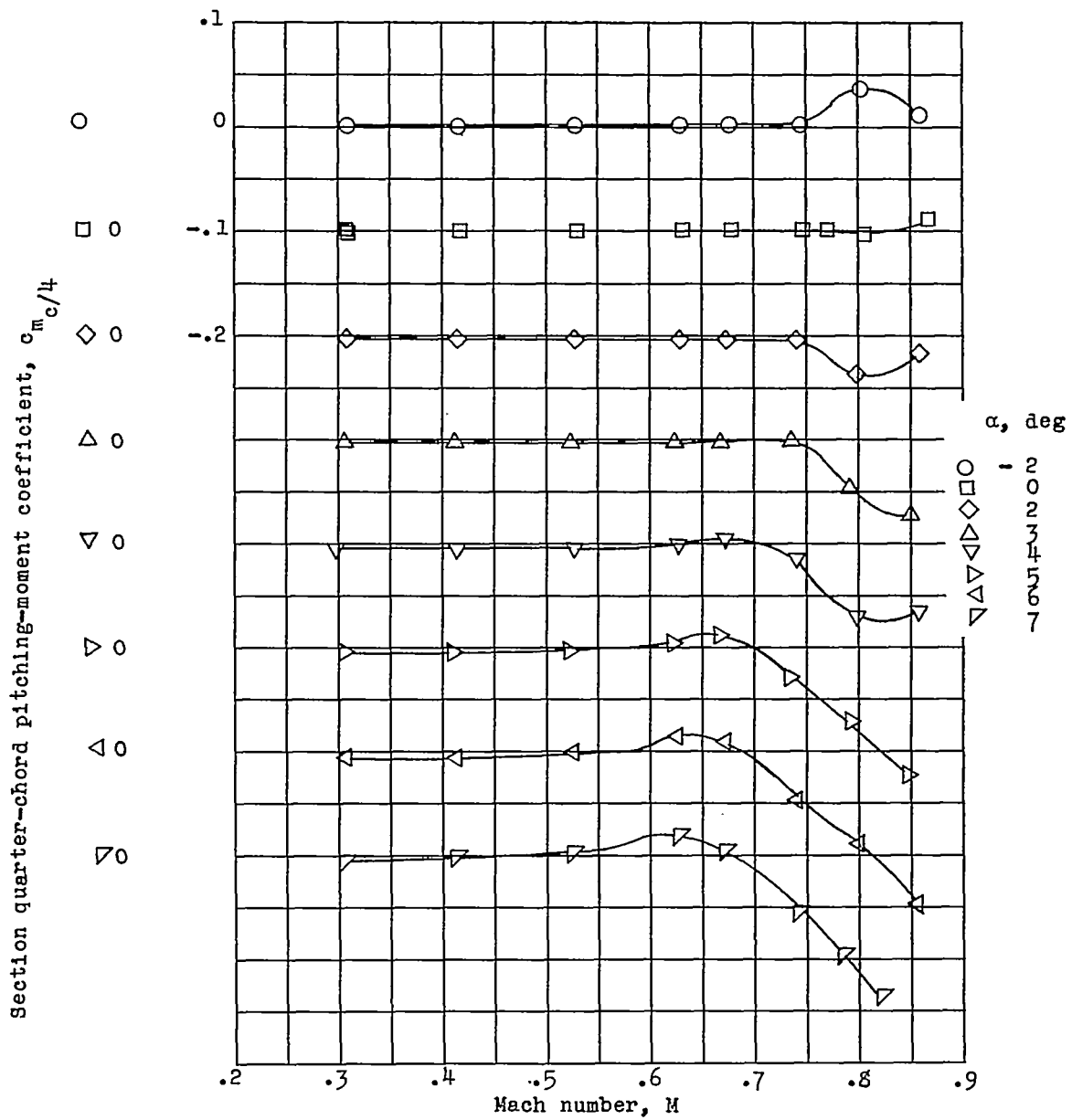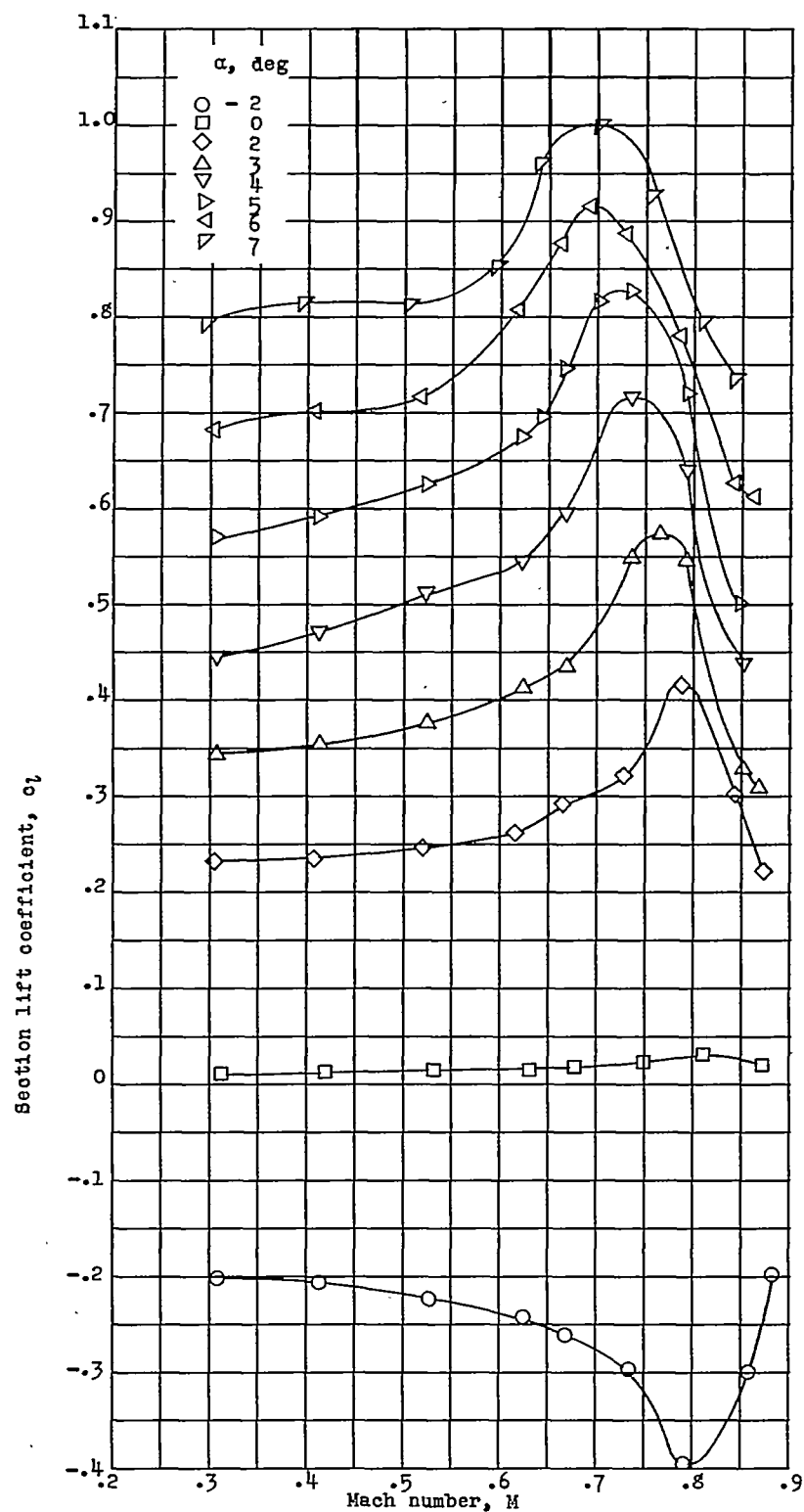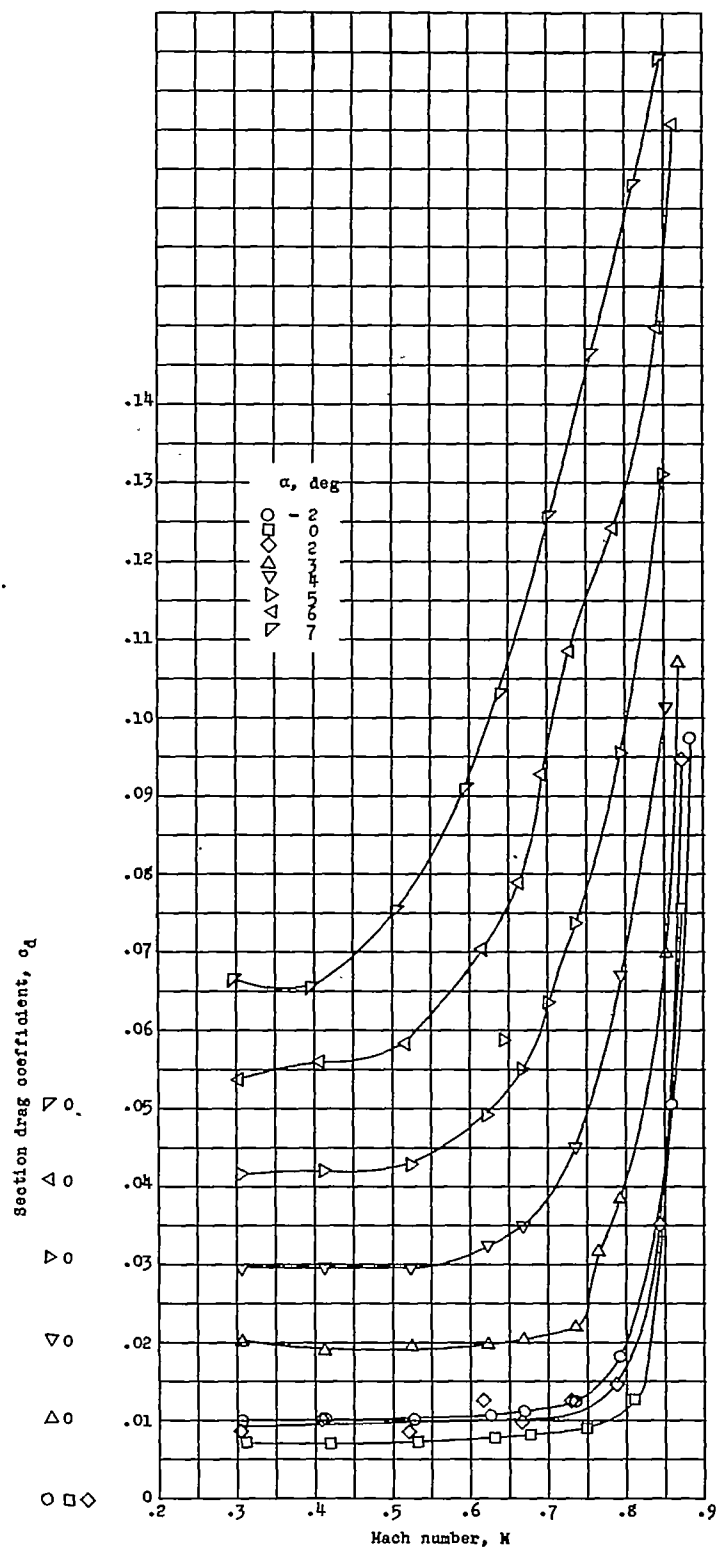
Figure 4.- Section drag coefficient of NACA 64-010 airfoil section as a function of Mach number for various angles of attack.

Figure 5.- Section quarter-chord pitching-moment coefficient of NACA 64-010 airfoil section as a function of Mach number for various angles of attack.

Figure 6.- Section lift coefficient of NACA 0010-1.10 40/1.051 airfoil
section as a function of Mach number for various angles of attack.

Figure 7.- Section drag coefficient of NACA 0010-1.10 40/1.051 airfoil
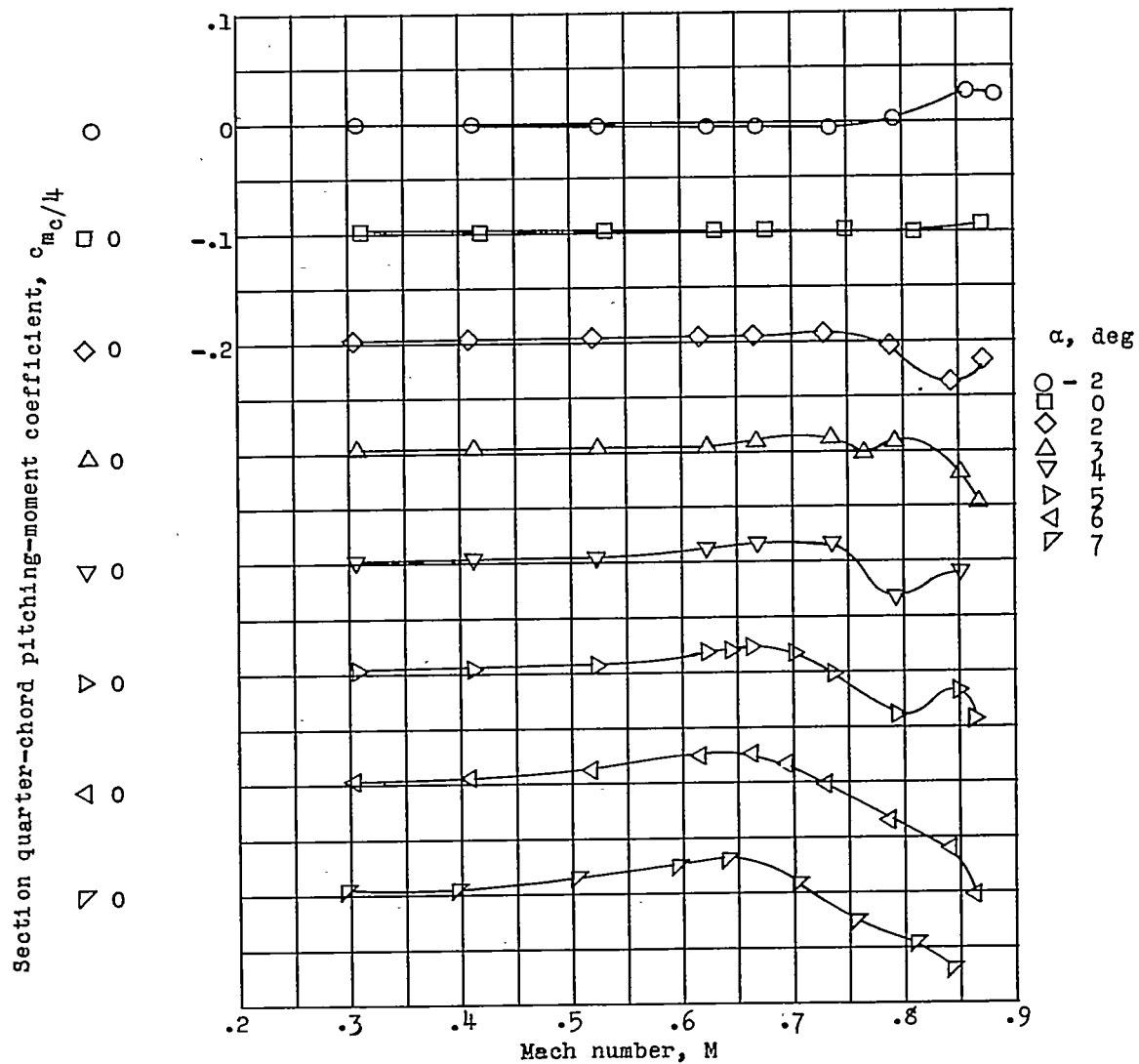section as a function of Mach number for various angles of attack.

Figure 8.- Section quarter-chord pitching-moment coefficient of NACA
0010-1.10 40/1.051 airfoil section as a function of Mach number
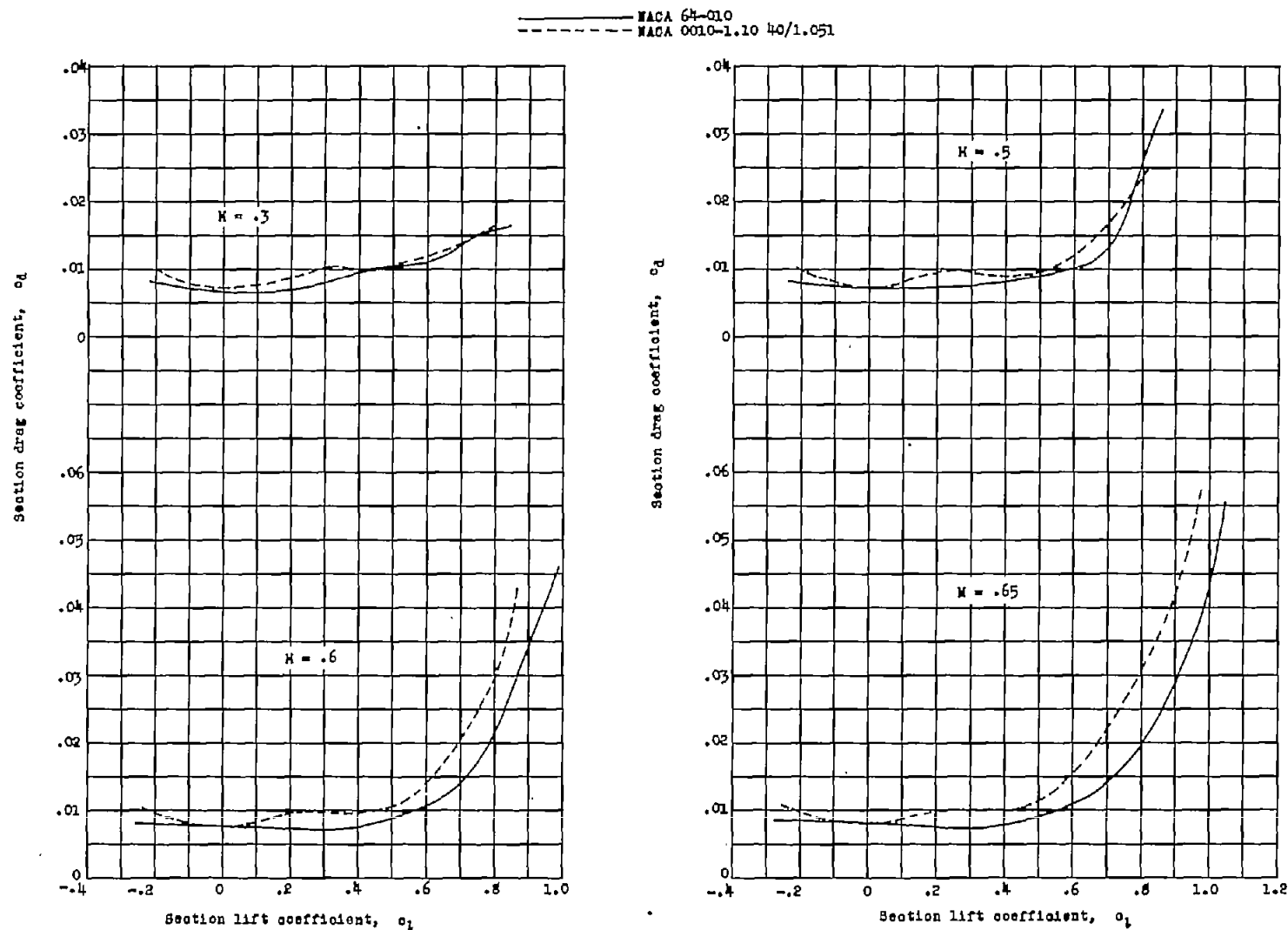for various angles of attack.

Figure 9.- Variation of section drag coefficient with section lift coefficient for NACA 64-010 and 0010-1.10 40/1.051 airfoil sections for several Mach numbers.
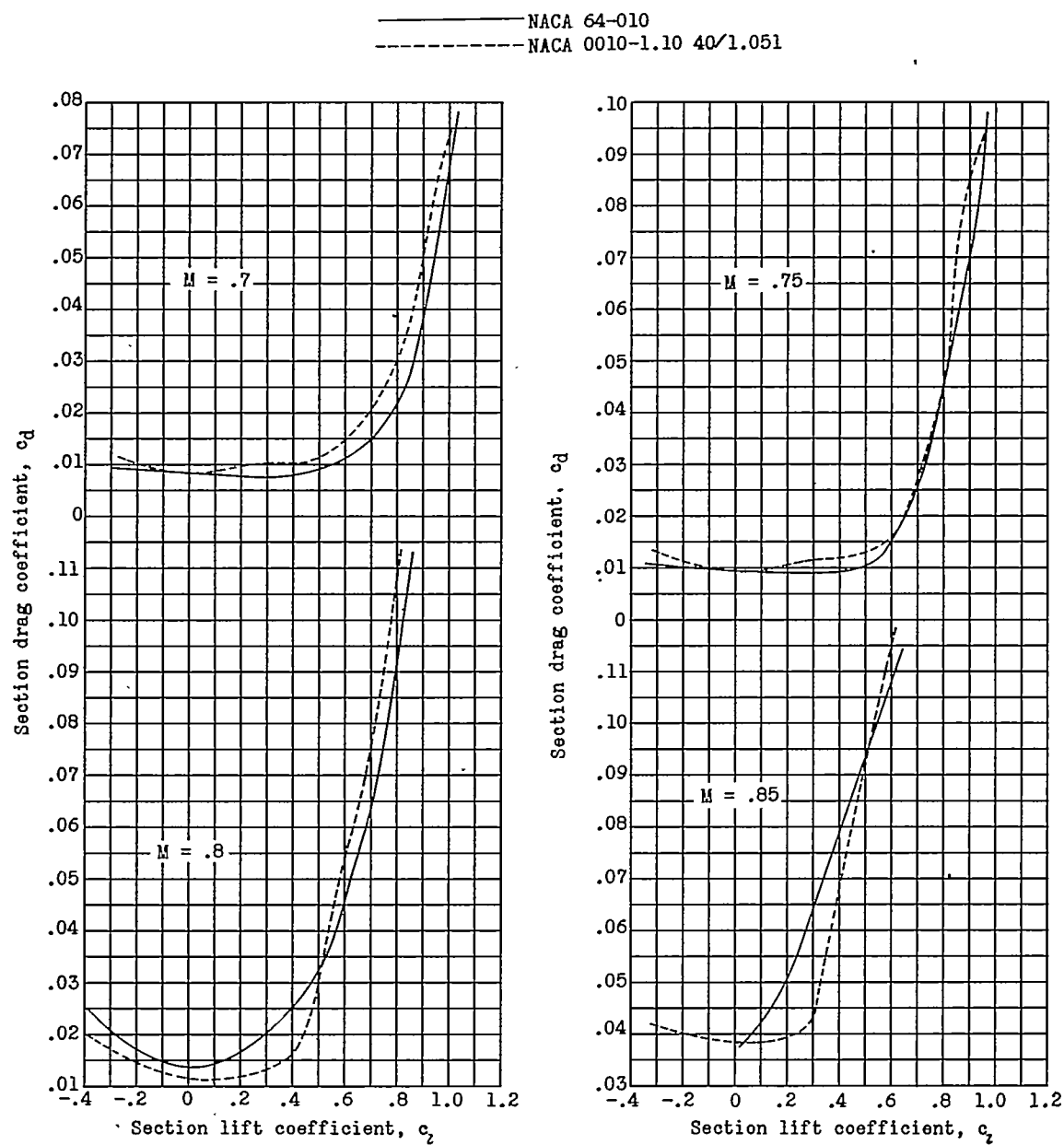
NACA 64-010
NACA 0010-1.10 40/1.051

Figure 9.- Concluded.

NACA 64-010 } Langley low-turbulence pressure tunnel

NACA 0010-1.10 40/1.051 } $R = 4.0 \times 10^6$ to 8.0×10^6

NACA 64-010 } Ames 1 × 3-1/2 ft. tunnel

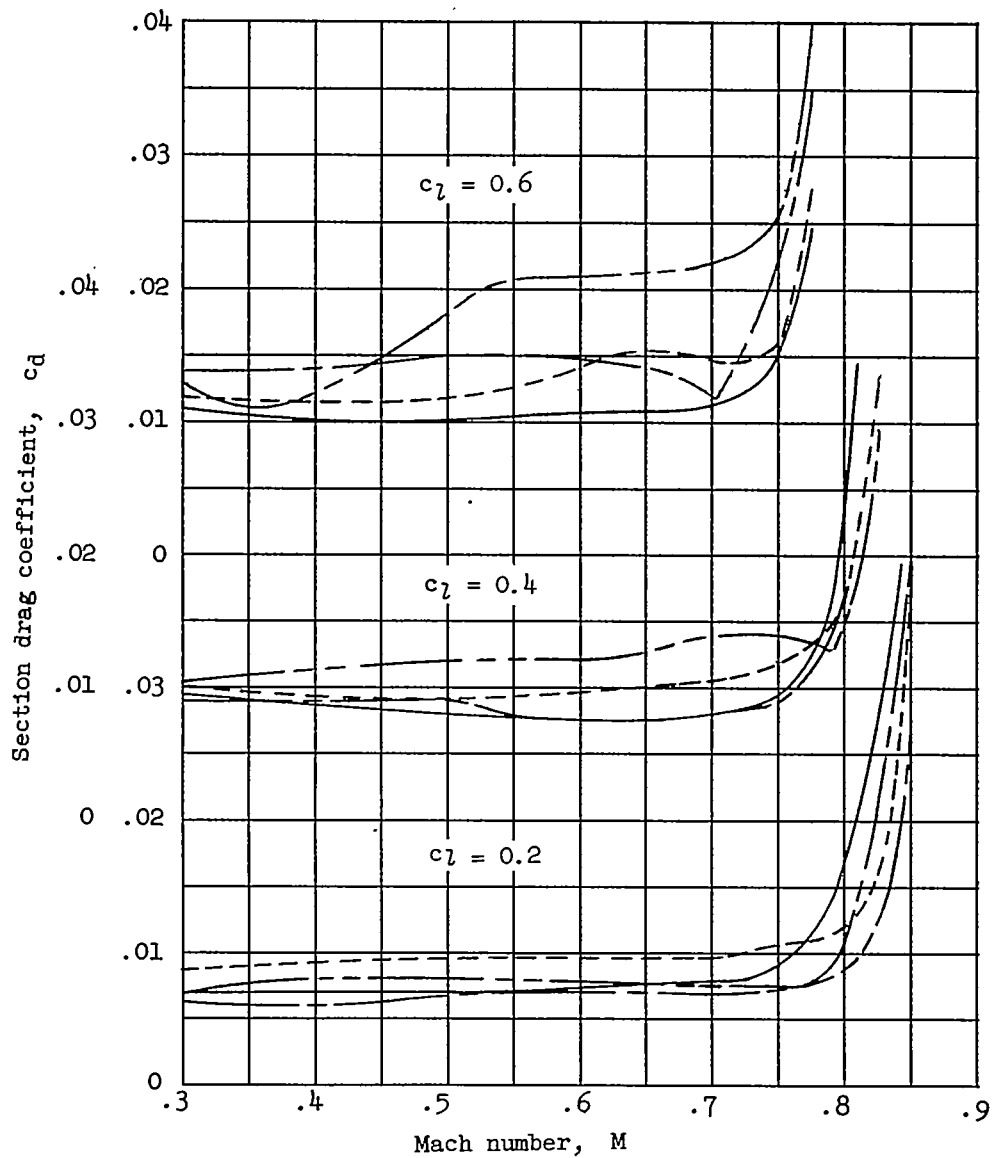NACA 0010-1.10 40/1.051 } $R = 1.0 \times 10^6$ to 2.0×10^6 (ref. 1)

Figure 10.- Effect of Reynolds number on variation of section drag coefficient with Mach number for NACA 64-010 and 0010-1.10 40/1.051 airfoil sections.